U.S. DEPARTMENT OF COMMERCE
National Technical Information Service
PB-289 185

Aquatic Sediments

(U.S.) Corvallis Environmental Research Lab, OR

Prepared for

Water Pollution Control Federation, Washington, DC

Jun 77

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3.
EPA-600/J-77-137	JOURNAL ARTICLE	PB 289185

4. TITLE AND SUBTITLE
Aquatic Sediments

5. REPORT DATE

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
C. F. Powers, W. D. Sanville, F. S. Stay, G. S. Schuytema

8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Corvallis Environmental Research Laboratory
200 S.W. 35th Street
Corvallis, Oregon 97330

10. PROGRAM ELEMENT NO.
1BA608

11. CONTRACT/GRANT NO.

12. SPONSORING AGENCY NAME AND ADDRESS
Water Pollution Control Federation
2626 Pennsylvania Avenue, NW
Washington, D.C. 20037

13. TYPE OF REPORT AND PERIOD COVERED
Literature Review, November, 1975-October, 1976

14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES
IN: JOURNAL WPCF, pp. 1316, June 1977.

16. ABSTRACT
One hundred seventeen literature references in the area of freshwater sediments were abstracted and synthesized to produce a review of sediment-related research for the period November, 1975 through October, 1976. Research areas covered included sediment-water interchange, sampling and analytical methods, chemical and physical characterization, biological considerations and modeling. The number of citations was about double those reviewed for the previous year.

REPRODUCED BY
NATIONAL TECHNICAL INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Sediments Nutrients Chemistry Toxicity	Sediment-water interchange, analytical methods, chemical characteristics of sediments, modeling sediment-water relationships.	06/F,M,R,T 07/B,C,D,E

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
Published in Jour. Water Pollution Control Fed., June 1977.		12
	20. SECURITY CLASS *(This page)*	22. PRICE A02-A01

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

EPA-600/J-77-137
JOURNAL ARTICLE

Literature Review

Aquatic sediments

C. F. Powers, W. D. Sanville, F. S. Stay, G. S. Schuytema

U. S. EPA, Corvallis, Ore.

SEDIMENT-WATER INTERCHANGE

A significant increase in sediment-related research was indicated by a doubling of the number of citations included in this year's review. The sediment-water interchange section reflects this through a three-fold increase. A NTIS literature search by Lehmann [1] yielded 106 abstracts (not listed here) on the release and adsorption of chemicals by sediments and how these pertain to water quality. Using multiple regression techniques, Haertel [2] correlated wind stress and nutrient levels and concluded that mixing was important in sediment-water nutrient cycling in some lakes. Bengtsson *et al.*[3] found lower P release rates from sediments from Lake Trummen (Sweden) following dredging and nutrient diversion. Oxygen and P concentrations in sediment were demonstrated by Fillos and Biswas [4] to affect P release. Sorption by sediments was observed under both aerobic and anaerobic conditions when P concentrations were very high. Andersen [5] observed that under aerobic conditions, an increase in pH from 8 to 9 increased PO_4 release from clays and other minerals. Bengtsson [6] showed no relation between the PO_4 concentration of interstitial water and that released from laboratory experiments, nor between the concentrations of PO_4, Fe, or Mn in the interstitial water and overlying bottom water. From analysis of a nutrient budget of Lake Kinneret (Israel), Serruya [7] demonstrated release of NH_3 but not P from the sediment under anaerobic summer conditions. During winter aerobic conditions, both P release and N fixation occurred. In a study of Lake Esrom, Denmark, Kamp-Nielsen [9] found nutrient exchange rates were governed mainly by temperature and sedimentation and to a lesser degree by redox and pH. Phosphate fixation and nitrification occurred in the aerobic littoral zones in contrast to high release of PO_4, NH_3, Fe, and denitrification in the anaerobic profundal zones. Banoub [9] determined release rates of reactive P were related to temperature, O_2, Fe, and Ca concentrations and increased when leachates from decomposing *Phragmites* were added. Release of sediment nitrogenous substances was demonstrated by Hrbacek and Procházková [10] to be indirectly proportional to the sediment-water ratio and, on a short-term basis, directly proportional to stirring rate. Release rate also varied with O_2 concentration. In Lake Wingra Isirimah *et al.*[11] found that contribution of N from the sediments was about the same magnitude as from external sources. Denitrification and immobilization of NO_3 within the sediments was rapid.

A study of Lake George (Uganda) by Viner [12] showed that in nutrient recycling nonbiogenic effects were the most important since low O_2 conditions led to a slow biological release of mineralized nutrients. Sebetich [13] built simplified ecosystems of water, diatoms, snails, and sand in an effort to model P exchange. Transfer of ^{32}P from water to sand was proportional to the water-sand interface, was little affected by snails, and significantly decreased by diatoms. Movement from sand to water was stopped by diatoms and unaffected by snails. Phosphorus release from sediment was observed by Davis *et al.*[14] to be unaffected by moderate populations of tubificids, which reduced the proportion of PO_4 in the interstitial water, and increased the rate of sediment uptake and the depth of P penetration. Wood [15] showed that movement of water by sediment macrobenthos was significant in the interchange of water and solutes. Lamarra [16] found that benthophagus fish contributed significantly to internal P loading and would be particularly important in shallow lakes with extensive littoral zones and highly organic sediment. Thomas [17] reviewed the relationship of macrobenthos to pollutants. Conclusions were that while the macrobenthos concentrate heavy metals and organics, the major role seems to be the resuspension of materials from below the sediment surface. Nichols and Keeney [18] compared N root and shoot uptake by *Myriophyllum spicatum* and found that rates were similar; however, the

biomass contained in each led to a much greater uptake by the shoot system. In Lake Trummen, *in situ* glucose turnover rates much greater than commonly found for water and sediments were determined by Fleischer.[19]

SAMPLING AND ANALYTICAL METHODS

Hakanson [20] developed a trap to collect sedimentary material from a lake bottom. Material collected over a known time was unaffected by bioturbation and yielded values for deposition rate which agreed closely with those obtained from cores. Using a perforated plastic tube containing a dialysis bag, Mayer [21] obtained representative samples of intersitial water when sufficient time was allowed for equilibration. Hesslein [22] constructed a dialysis apparatus which sampled interstitial water at about 10 mm intervals. Rudd and Hamilton [23] developed a sediment gas sampler to monitor concentrations by equilibration of dissolved interstitial water gases with water inside the sampler tubing. Bancroft *et al.*[24] developed an ATP extraction method for a variety of marine sediments. Recoveries from clay, calcareous, and mangrove-litter sediments and from pure algal cultures exceeded those obtained by other extraction techniques. A rapid method for measuring the activity of nitrifying bacteria in sediment with incubation times of a few hours was reported by Billen.[25] Andersen [26] compared muffle furnace ignition and perchloric acid digestion methods for P determination in sediments. Values obtained by both were similar except in sediments high in humates. A modified two-step procedure for NO_3 determination in sediments and some natural waters was devised by Afghan and Ryan.[27] Interfering substances were removed prior to colorimetric analysis of nitrite.

Farrington and Tripp [28] compared three procedures for hydrocarbon extraction from sediments. Methanol:benzene extraction with and without HCl pretreatment and alkaline hydrolysis extraction all provided reliable estimates of fuel oil hydrocarbons. Total mercury in the surficial sediments of Mersey Estuary (England) was analyzed by Craig and Morton [29] using cold vapor atomic absorption spectrophotometry following digestion and oxidation. Kim *et al.*[30] developed a rapid method for the determination of Mo in soils, sediments, and natural water employing atomic absorption spectroscopy. X-ray fluorescence was used by Kulkarni and Preiss [31] for rapid assay of the trace element content of lake sediment. Predigestion or chemical treatment was precluded, and results were similar to those obtained by atomic absorption methods.

CHEMICAL AND PHYSICAL CHARACTERIZATION

Williams *et al.*[32] differentiated P in Lake Erie sediments into apatite, nonapatite inorganic, and organic forms, which were compared to reactive Fe, organic C, Mn, and clay content. Vertical distribution of these P forms was then compared to dated horizons by Williams *et al.*[33] to determine relative rates of accumulations from precolonial times to the present. Poon and Sheih [34] detected nutrient enrichment in surficial sediments of Narragansett Bay. An increase in NH_3 and P species with sediment depth was attributed to anaerobic conditions, chemical transformations, and inaccessibility to overlying water. Viner [35] found that Lake George (Uganda) sediments sorb substantial quantities of PO_4 and suggested that resuspension might reduce PO_4 concentration in the lake water. Further, Viner [36] observed that Fe, Ca, pH and dissolved organic material affected P precipitation. In a laboratory microcosm study, Patrick *et al.*[37] characterized NO_3 removal mechanisms from water at the water-mud interface under varying oxidizing and reducing conditions. In studies on a variety of sediments, Terry and Nelson [38] found that denitrification was not affected by water-sediment ratio or dissolved oxygen (DO) content of the overlying water if the sediment remained anaerobic. An organic C balance was presented by Jordan and Likens,[39] and sedimentation losses were 7 percent of the total C input to a New Hampshire Lake.

Ripl [40] concluded that *in situ* oxidation of polluted lake sediments improved their P binding capacity and reduced degradable organic matter. Evidence of O_2 mixing to a sediment depth of at least 100 mm was observed by Viner.[41] Organic decomposition within the sediments of Lake George depended upon oxygen penetration as a function of turbulent wind induced mixing. Lipid distribution in salt marsh sediments was studied by Swetland and Wehmiller.[42] Some pathway unique to salt marshes was responsible for large quantities of long-chain fatty acids. Boon *et al.*[43] concluded that phytenic acid and dihydrophytol may be of diagnostic value in the organic geochemistry of recent sediments if their occurrence were mutually exclusive. Stanols in sediment cores from Lake Suwa (Japan) were suggested by Nishimura and Koyama [44] to

originate from the diatom *Melosira granulata*. Whelan *et al.*[46] studied the chemical effects of chronic petroleum input into a marsh. Results indicated that microbial processes were responsible for petroleum decomposition, and that dissolved organic C may be a more significant measure of chronic petroleum input than hydrocarbons. Lake Washington surface sediments were shown by Wakeham and Carpenter [48] to contain aliphatic hydrocarbons; a large component of petroleum hydrocarbons was suggested. Increased hydrocarbon levels corresponded with adjacent metropolitan growth.

Schindler and Alberts [47] concluded that sedimentary humic materials were not important in cation burial but may function as an intermediate electron transport system in anaerobic sediments which appear to be significant in metal reduction. The composition of fibrous cummingtonite in Lake Superior surficial sediments was reported by Kramer [49] to approach the mean of that added from taconite tailings and a zeta potential approaching zero. A gradient from shore was suggested to be due to a mixed compositional source of cummingtonite and preferential coagulation and sedimentation of the iron-rich variety. Tessenow and Baynes [49] related the formation of Fe and Mn oxide accumulations to upward diffusion of the soluble forms through interstitial water into an oxidized surficial layer maintained by oxygen transported through *Isoetes lacustris* L. Dean and Gorham [50] classified Minnesota lakes according to the proportions of organic matter, $CaCO_3$ and clastic materials in the profundal sediments. Variations among lakes were related to aridity, aquatic productivity, glacial drift, and erosion. The importance of identifying natural or artificial sources of materials to a lake that could mistakenly be attributed to nuclear generating plants was emphasized by Rossmann.[51] Glass and Poldoski [52] demonstrated increases in Si, Ca, Mn, Na, K, and Mg; decreases in O_2; and no change in Cu, Fe, and P in undisturbed Lake Superior water-sediment cores after 1 600 hours of incubation. The release of S from Lake Ontario sediments was reported by Nriagu and Coker [53] to be only 2 percent of that annually precipitated. Norton and Sasseville [54] measured sediment-water interactions and found higher concentration gradients of elements than previously observed, a zone of high element concentration near the sediment surface, comparability of closely spaced cores and incomparability of cores from different areas of the same lake or from different lakes. Spatial variations in Chesapeake Bay cores were reported by Matisoff *et al.*[55] to be only slightly greater than the limits set by analytical techniques. Parameters which were conservative or influenced predominantly by inorganic processes were altered mainly by seasonal variations in salinity and temperature while those related to organic decomposition were generally related to season. Chittenden *et al.*[56] noted that Ca, Mg, K, N, and S concentrations were higher in weed bed sediments than in deeper areas; however, Fe and Mn were lower. Vertical redistribution of some elements was similar to soil horizons. Sediment chemistry was correlated with the presence of European man in four Maine lakes studied by Sasseville *et al.*[57] A "reactive layer" containing high dissolved nutrient concentrations was suggested as a nutrient reserve.

Edgington and Robbins [58] determined the distribution of stable Pb in Lake Michigan cores using ^{210}Pb and described the distribution by a mathematical model. It was suggested that measurement of stable Pb and ^{210}Pb fluxes in the same core might be used to separate atmospheric and terrigenous inputs. Hayle Estuary (England) sediments were observed by Yim [59] to contain high concentrations of Sn, As, Cu, Pb, W, and Zn. Vertical distribution was correlated with changes in mining intensity and estuarine geomorphological evolution. Heavy metals in sediments of a Montana reservoir receiving mining and smelter wastes were studied by Bailey and Weisel.[60] Relatively high levels of Cu, Zn, and Mn were found and peak concentrations of Cu, Zn, Mn, and Fe at the same depth were associated with changes in mining and smelter operations. Wheeler and Dunning [61] found that industrialization increased Cr, Cu, and Zn concentrations in the surficial sediments of four western Michigan lakes. Relatively high Cr and Ni concentrations in the Ticonderoga and Malletts Bay areas of Lake Champlain were attributed to industrial pollution by Hunt.[62] Fitchko and Hutchinson [63] analyzed sediment samples from the mouths of 116 watercourses entering the Great Lakes for ten heavy metals. Elevated concentrations corresponded with urban-industrial activity.

Miller [64] showed that mercuric ion in pond sediment was reduced to elemental Hg and released back into the water in the presence of humic acid. The major source of Hg in surficial sediments of Lake Erie was reported by Thomas and Jaquet [65] to be the Detroit River.

Organic C and Hg were directly correlated. Ramamoorthy and Rust [66] found that the bonding coefficient of Hg was strongly correlated with the sediment organic content. Sorption was not affected by pH, and desorption by water or fluvic acid was very slow. Net methylmercury production was noted by Olson and Cooper [67] to be greater under anaerobic than aerobic conditions in three different San Francisco Bay sediments. Organic matter greatly affected methylation. Mortimer and Kudo [68] added Hg to the water of aquaria containing *Elodea* growing in sediment or glass beads and to plant-free aquaria. Plants growing in sediment absorbed significantly less Hg than those growing in beads, and sediment from which the plants had been removed contained about twice as much Hg as plant-free sediment. Chau *et al.*[69] reported conversion of Se compounds to volatile forms by lake sediment microorganisms and emphasized the significance of such transformations. Sediment samples from estuarine areas were exposed to laboratory leaching and natural weathering by Burrows and Hulbert.[70] Leaching of Cd, Zn, and Pb were considered important in evaluating dredge spoils for wildlife habitat construction. Brannon *et al.*[71] compared concentrations of five metals in marine, estuarine, and freshwater sediments using a standard elutriate test. Sediment from old lignite pits examined by Fjerdingstad *et al.*[72] contained 50 percent Fe on a dry weight basis. Oxidation of S and Fe had not decreased 28 years after mining ceased. Jackson and Nichol [73] investigated the potential of lake sediment geochemistry in evaluating the availability of trace elements in the bedrock of northwest Canada. Klassen *et al.*[74] determined factors affecting metal dispersion in the sediments of six Canadian Shield lakes. Organic content was low and horizontal bands of precipitated Fe and Mn were distinct.

Plato and Jacobson [75] described the areal distribution of ^{137}Cs in southeastern Lake Michigan and found it a fair to good tracer for many man-made materials. Scavenging of $^{239, 240}Pu$ and ^{137}Cs was found by Edgington and Robbins [76] to occur at the same overall rate in Lake Michigan; total content strongly correlated with the mass sedimentation rate. Sediment profiles suggested a redistribution of deposited radioactivity. Edgington *et al.*[77] described the vertical distribution of $^{239, 240}Pu$ and ^{137}Cs in Lake Michigan cores. Comparisons indicated a common removal mechanism and chemical mobility of Pu was predominantly associated with hydrous Fe and Mn oxides. Americium-241 was formed *in situ* and had no preferential mobility over Pu. Preferential adsorption of ^{137}Cs to the micaceous component of stream sediments was observed by Francis and Brinkley.[78] Density-gradient centrifugation was used to separate sufficient quantities of the muscovite mica component for ^{137}Cs determination. Noyce *et al.*[79] discussed the development and production of a radioactivity standard reference material (SRM4350) for freshwater sediments. The radioactivities of 28 nuclides in the standard have been measured of which 10 are certified.

In 4-week static laboratory studies, Kobylinski and Livingston [80] found Mirex contaminated sediments retained virtually all the insecticide; however, about 40 percent was lost under constant flow conditions. Fulk *et al.*[81] found PCB's, Dieldrin, and DDT commonly in freshwater and marine sediments from various locations in the U. S. In laboratory experiments sediment to water ratios of 1:10 or less resulted in negligible transfer of pesticides. Studies by Choi and Chen [82] on Los Angeles Harbor sediments showed a linear relationship between the concentration of chlorinated hydrocarbons and total organic C.

Studies of the physical and chemical characteristics of Lake Erie sediment cores by Kemp *et al.*[83] showed surface enrichment of metals and nutrients from anthropogenic loading since 1850. Sasseville and Norton [84] investigated vertical variations in sediment and interstitial water chemistry in four Maine lakes and related such variations to cultural history. Ludlam [85] found that laminated sediments were best developed in lakes subject to prolonged hypolimnetic anoxia, apparently because of the limited activity of benthos. Scanning electron microscopy and X-radiography of microstratification in sediments were used by Edmondson [86] to obtain information on past short-term changes in Lake Washington. McLachlan and McLachlan [87] found that in two newly formed lakes with nonvegetated basins, the sediment layer formed initially from the rearrangement of inorganic particles according to size. A bibliography compiled by Brown [88] contains 105 abstracts (not listed here) on the process and effects of sedimentation in reservoirs and lakes. Cores from an unglaciated Alaskan lake were used by Noltimier and Colinvaux [89] in discovering the Imuruk geomagnetic excursion. Thompson *et al.*[90] showed initial magnetic susceptibility of lake sediments to be a function of detrital titanomagnetite. Susceptibility was parallel and synchronous from core

to core, therefore providing a valuable basis for core correlation. Lewis [91] studied water column and surficial sediment temperatures of southeastern U. S. lakes for two years and determined the surface sediments were warmer than the overlying water during lake heating and cooling periods. Thomas *et al.*[92] defined three distinct sedimentary regions in Lake Erie, corresponding to the principal lake basins. Mean grain size was used to predict clay content and hence clay-associated geochemical elements. In a seismic survey of Lake Champlain sediments, Dowling [93] determined maximum thickness of unconsolidated sediment and sedimentation rates.

BIOLOGICAL CONSIDERATIONS

Molongoski and Klug [94] suggested that Wintergreen Lake (Michigan) sediments were being metabolized by the bacterium *Clostridium*. Electron transport analysis was found by Zimmerman [95] to be useful in analyzing the relationship between biological and chemical reactions in sediments. Hood *et al.*[96] showed the ratio of hydrocarbon-utilizing bacteria to be correlated with the absolute and relative levels of hydrocarbons in salt marsh sediments. In an area continuously exposed to oil spills, Walker *et al.*[97] found a greater variety of petroleum-degrading bacteria in the water than in the sediment. Zeikus and Winfrey [98] observed that the rate of sediment methanogenesis in Lake Mendota varied with location, depth, date, temperature, and number of methanogens. In studies on the effect of oxides of N on methanogenesis in salt marsh sediments and whole cell suspensions, Balderston and Payne [99] found that nitrous oxide was most inhibitory upon sediments while nitric oxide had the most effect upon whole cell cultures. Furukawa and Matsumura [100] isolated a bacterial strain capable of breaking down chlorinated biphenyls; degradation was generally inversely related to degree of chlorination. Clesceri and Daze [101] concluded that DNA measurements have applicability as a biomass indicator in lake sediments. Laboratory sedimented algal components were compared by Cranwell [102] with corresponding components from fresh cells to identify compounds which might be used as markers of autochthonous material in sediment. Gorham and Sanger [103] concluded that most of the sedimentary organic matter in productive lakes was derived from phytoplankton and aquatic macrophytes. High concentrations of oscillaxanthin in Lake Washington sediments were associated with high *Oscillatoria* productivity by Griffiths and Edmondson.[104] Philp and Calvin [105] reported kerogen-like precursors, probably derived from algal material, in certain types of recent organically rich sediment. Rich [106] noted that benthic respiratory quotients increased in sediments with the duration of stratification, suggesting a relationship between redox potential, redox capacity, and composition of organic matter. High oxygen uptake rates during restratification in reconstituted cores from a lake and a marine bay were interpreted by Hargrave [107] to indicate that chemical oxidation was later replaced by biological respiration. Miller and Reed [108] found an inverse relationship between organic matter and respiration rates in pond sediments. In an investigation of oxygen demand by the benthic community, Neame [109] observed that microbial and chemical uptake were the most significant. Photosynthesis in the surficial sediment was a more important source of O_2 than diffusion from the water. Pamatmat [110] attempted to measure *in situ* benthic community metabolism but found no single technique which produced an accurate measurement.

MODELING

Holdren *et al.*[111] developed a model for the prediction of dissolved Mn distribution in the anaerobic interstitial waters of Chesapeake Bay sediments. A model utilizing time-varying P loadings, spatial variation of grain size, and wave turbulence developed by Lam and Jaquet [112] showed that under high wind conditions P regeneration resulted from wave resuspension of sediments. Hart *et al.*[113] developed a simple model to predict sediment total P values in Lake Mulwala (Australia). In an attempt to determine tracers for exchange across the sediment-water interface, Hammond *et al.*[114] successfully utilized a two layered model by Feng which accounted for stirring by currents and organisms. Thibodeaux and Cheng [115] extended a previously used Fourier type, semi-infinite slab energy model to include a Fickian type model for the upsurge of nutrients from the sediment-water interface in lakes. A simulation model developed by Bookhout and White [116] from Lake Erie marsh data allowed environmental variations to influence tritium kinetics. Lehman [117] presented several models to correct for basin morphometry effect on sediment depositional rates. The models allow the determination of basinwide influx rates and the impact of sediment focusing.

REFERENCES

1. "Sediment Water Interaction and Its Effect Upon Water Quality. A Bibliography with Abstracts." E. J. Lehmann [Ed.], NTIS/PS-76/0021 (1976).
2. Haertel, L., "Nutrient Limitation of Algal Standing Crops in Shallow Prairie Lakes." *Ecology*, 57, 664 (1976).
3. Bengtsson, L., *et al.*, "Lake Trummen Restoration Project I. Water and Sediment Chemistry." *Verh. Internat. Verein. Limnol.* (Ger.), 19, 1080 (1975).
4. Fillos, J., and Biswas, H. "Phosphate Release and Sorption by Lake Mohegan Sediments." *Amer. Soc. Civil. Engr., J. Envir. Engr. Div.*, 2, 239 (1976).
5. Andersen, J. M., "Influence of pH on Release of Phosphorus from Lake Sediments." *Arch. Hydrobiol.* (Ger.), 76, 411 (1975).
6. Bengtson, L., "Phosphorus Release From a Highly Eutrophic Lake Sediment." *Verh. Internat. Verein. Limnol.* (Ger.), 19, 1107 (1975).
7. Serruya, C., "Nitrogen and Phosphorus Balances and Load-Biomass Relationships in Lake Kinneret (Israel)." *Verh. Internat. Verein. Limnol.* (Ger.), 19, 1357 (1975).
8. Kamp-Nielsen, L., "Seasonal Variation in Sediment-Water Exchange of Nutrient Ions in Lake Esrom." *Verh. Internat. Verein. Limnol.* (Ger.), 19, 1057 (1975).
9. Banoub, M. W., "Experimental Studies on Material Transactions Between Mud and Water of the Gnadensee (Bodensee)." *Verh. Internat. Verein. Limnol.* (Ger.), 19, 1263 (1975).
10. Hrbacek, J., and Prochazkova, L., "Release of Nitrogenous Substances from Bottom Sediments Under Laboratory Conditions." *Verh. Internat. Verein. Limnol.* (Ger.), 19, 1899 (1975).
11. Isirimah, N. O., *et al.*, "Nitrogen Cycling in Lake Wingra." *Jour. Environ. Qual.*, 5, 182 (1976).
12. Viner, A. B., "The Sediments of Lake George (Uganda) II: Release of Ammonia and Phosphate from an Undisturbed Mud Surface." *Arch. Hydrobiol.* (Ger.), 76, 368 (1975).
13. Sebetich, M. I., "Phosphorus Kinetics of Freshwater Microcosms." *Ecology*, 56, 1262 (1975).
14. Davis, R. B., *et al.*, "Effects of Burrowing Tubificid Worms on the Exchange of Phosphorus Between Lake Sediment and Overlying Water." *Verh. Internat. Verein. Limnol.* (Ger.), 19, 382 (1975).
15. Wood, L. W., "Role of Oligochaetes in the Circulation of Water and Solutes Across the Mud-Water Interface." *Verh. Internat. Verein. Limnol.* (Ger.), 19, 1530 (1975).
16. Lamarra, V. A., Jr., "Digestive Activities of Carp as a Major Contributor to the Nutrient Loading of Lakes." *Verh. Internat. Verein. Limnol.* (Ger.), 19, 2461 (1975).
17. Thomas, N. A., "Accumulation and Transport of Energy-Related Pollutants by Benthos." Proc. of the Second Federal Conf. on the Great Lakes, Great Lakes Basin Commission, 361–368 (1975).
18. Nichols, D. S., and Keeney, D. R., "Nitrogen Nutrition of *Myriophyllum spicatum*: Uptake and Translocation of ^{15}N by Shoots and Roots." *Freshwater Biol.* (G. B.), 6, 145 (1976).
19. Fleischer, S., "Sugar Turnover in Lake Water and Sediments." *Verh. Internat. Verein. Limnol.* (Ger.), 19, 2837 (1975).
20. Hakanson, L., "A Bottom Sediment Trap for Recent Sedimentary Deposits." *Limnol. & Oceanog.*, 21, 170 (1976).
21. Mayer, L. M., "Chemical Water Sampling in Lakes and Sediments with Dialysis Bags." *Limnol. & Oceanog.*, 21, 909 (1976).
22. Hesslein, R. H., "An *in situ* Sampler for Close Interval Pore Water Studies." *Limnol. & Oceanog.*, 21, 912 (1976).
23. Rudd, J. W. M., and Hamilton, R. D., "Two Samplers for Monitoring Dissolved Gases in Lake Water and Sediments." *Limnol. & Oceanog.*, 20, 902 (1975).
24. Bancroft, K., *et al.*, "The Extraction and Measurement of Adenosine Triphosphate from Marine Sediments." *Limnol. & Oceanog.*, 21, 473 (1976).
25. Billen, G., "Evaluation of Nitrifying Activity in Sediments by Dark ^{14}C-Bicarbonate Incorporation." *Water Res.* (G. B.), 10, 51 (1976).
26. Andersen, J. M., "An Ignition Method for Determination of Total Phosphorus in Lake Sediments." *Water Res.* (G. B.), 10, 329 (1976).
27. Afghan, B. K., and Ryan, J. F., "A Modified Procedure for the Determination of Nitrate in Sediments and Some Natural Waters." *Environ. Letters*, 9, 59 (1975).
28. Farrington, J. W., and Tripp, B. W., "A Comparison of Analysis Methods for Hydrocarbons in Surface Sediments." *In:* Church, T. M. [Ed.], Marine Chemistry in the Coastal Environment. American Chemical Society Symposium Series 18, 267–284 (1975).
29. Craig, P. J., and Morton, S. F., "Mercury in Mersey Estuary Sediments, and the Analytical Procedure for Total Mercury." *Nature* (G. B.), 261, 125 (1976).
30. Kim, C. H., *et al.*, "Use of Long-Chain Alkylamines for Preconcentration and Determination of Traces of Molybdenum, Tungsten, and Rhenium by Atomic-Absorption Spectroscopy—II. Molybdenum in Soils, Sediments and Natural Waters." *Talanta* (G. B.), 23, 229 (1976).

31. Kulkarni, P. V., and Preiss, I. L., "Use of Radioisotope Induced X-Ray Fluorescence for Environmental Studies." *Jour. Radioanal. Chem.*, 24, 423 (1975).
32. Williams, J. D. H., *et al.*, "Forms of Phosphorus in the Surficial Sediments of Lake Erie." *Jour. Fish. Res. Bd. Can.*, 33, 413 (1976).
33. Williams, J. D. H., *et al.*, "Rates of Accumulation of Phosphorus Forms in Lake Erie Sediments." *Jour. Fish. Res. Bd. Can.*, 33, 430 (1976).
34. Poon, C. P. C., and Sheih, J. M. S., "Nutrient Profiles of Bay Sediment." *Jour. Water Poll. Control Fed.*, 48, 2007 (1976).
35. Viner, A. B., "The Sediments of Lake George (Uganda) III. The Uptake of Phosphate." *Arch. Hydrobiol.* (Ger.), 76, 393 (1975).
36. Viner, A. B., "Non-biological Factors Affecting Phosphate Recycling in the Water of a Tropical Eutrophic Lake." *Verh. Internat. Verein. Limnol.* (Ger.), 19, 1404 (1975).
37. Patrick, W. H., Jr., *et al.*, "Nitrate Removal From Water at the Water-Mud Interface in Wetlands." USEPA Ecological Research Series Report No. EPA-600/3-76-042, Office of Research and Development (1976).
38. Terry, R. E., and Nelson, D. W., "Factors Influencing Nitrate Transformations in Sediments." *Jour. Environ. Qual.*, 4, 549 (1975).
39. Jordan, M., and Likens, G. E., "An Organic Carbon Budget for an Oligotrophic Lake in New Hampshire, U. S. A." *Verh. Internat. Verein. Limnol.* (Ger.), 19, 994 (1975).
40. Ripl, W., "Biochemical Oxidation of Polluted Lake Sediment With Nitrate—A New Lake Restoration Method." *Ambio* (Swed.), 5, 132 (1976).
41. Viner, A. B., "The Sediments of Lake George (Uganda) I: Redox Potentials, Oxygen Consumption and Carbon Dioxide Output." *Arch. Hydrobiol.* (Ger.), 76, 181 (1975).
42. Swetland, P. J., and Wehmiller, J. F., "Lipid Geochemistry of Recent Sediments from the Great Marsh, Lewes, Delaware." *In*: Church, T. M. [Ed.], Marine Chemistry in the Coastal Environment. American Chemical Society Symposium Series 18, 285–303 (1975).
43. Boon, J. J., *et al.*, "Phytenic Acid in Sediments." *Nature* (G. B.), 258, 414 (1975).
44. Nishimura, M., and Koyama, T., "Stenols and Stanols in Lake Sediments and Diatoms." *Chem. Geol.*, 17, 229 (1976).
45. Whelan, T., III, *et al.*, "Long-Term Chemical Effects of Petroleum in South Louisiana Wetlands—1. Organic Carbon in Sediments and Waters." *Marine Poll. Bull.* (G. B.), 7, 150 (1976).
46. Wakeham, S. G., and Carpenter, R., "Aliphatic Hydrocarbons in Sediments of Lake Washington." *Limnol. & Oceanog.*, 21, 711 (1976).
47. Schindler, J. E., and Alberts, J. J., "An Investigation of the Role of Organic Materials in Freshwater Systems." *Verh. Internat. Verein. Limnol.* (Ger.), 19, 2201 (1975).
48. Kramer, J. R., "Fibrous Cummingtonite in Lake Superior." *Can. Mineral.*, 14, 91 (1976).
49. Tessenow, U., and Baynes, Y., "Redox-Dependent Accumulation of Fe and Mn in a Littoral Sediment Supporting *Isoetes lacustris* L." *Naturwissenschaften* (Ger.), 62, 342 (1975).
50. Dean, W. E., and Gorham, E., "Major Chemical and Mineral Components of Profundal Surface Sediments in Minnesota Lakes." *Limnol. & Oceanog.*, 21, 259 (1976).
51. Rossmann, R., "Chemistry of Nearshore Surficial Sediments from Southeastern Lake Michigan." Univ. of Mich. Great Lakes Res. Div. Spec. Rpt. No. 57 (1975).
52. Glass, G. E., and Poldoski, J. E., "Interstitial Water Components and Exchange Across the Water Sediment Interface of Western Lake Superior." *Verh. Internat. Verein. Limnol.* (Ger.), 19, 405 (1975).
53. Nriagu, J. O., and Coker, R. D., "Emission of Sulfur from Lake Ontario Sediments." *Limnol. & Oceanog.*, 21, 485 (1976).
54. Norton, S. A., and Sasseville, D. R., "Flux of Nutrients by Diffusion Through the Lake Sediment-Hypolimnion Interface for 9 Lakes in Maine, U. S. A." *Verh. Internat. Verein. Limnol.* (Ger.), 19, 372 (1975).
55. Matisoff, G., *et al.*, "Spatial and Temporal Variations in the Interstitial Water Chemistry of Chesapeake Bay Sediments." *In*: Church, T. M. [Ed.], Marine Chemistry in the Coastal Environment. American Chemical Society Symposium Series 18, 343–363 (1975).
56. Chittenden, E. T., "Sediments of Lake Rotoroa and Rotoiti, South Island, New Zealand." *N. Z. Jour. Marine & Freshwater Res.*, 10, 61 (1976).
57. Sasseville, D. R., *et al.*, "Comparative Interstitial Water and Sediment Chemistry in Oligotrophic and Mesotrophic Lakes, Maine, U. S. A." *Verh. Internat. Verein. Limnol.* (Ger.), 19, 367 (1975).
58. Edgington, D. N., and Robbins, J. A., "Records of Lead Deposition in Lake Michigan Sediments Since 1800." *Environ. Sci. & Technol.*, 10, 266 (1976).
59. Yim, W. W.-S., "Heavy Metal Accumula-

tion in Estuarine Sediments in a Historical Mining of Cornwall." *Marine Poll. Bull.* (G. B.), 7, 147 (1976).

60. Bailey, A. K., and Weisel, G. F., "Concentration of Heavy Metals in Sediments of a Hydroelectric Impoundment." Montana State University Water Resources Research Center, Report W76-09755, Project No. OWRT-A-088-MONT (1976); NTIS PB-254 549/9SL.
61. Wheeler, R., and Dunning, C., "Trace-Element Geochemistry of Piston Cores from Western Michigan Coastal Lakes." *Can. Mineral.*, 14, 23 (1976).
62. Hunt, A. S., "Sediment Properties, Lake Champlain: 1971–1975." University of Vermont, Completion Report W76-09763, Project No. OWRT-A-015-VT (1975); NTIS PB-254 546/5SL.
63. Fitchko, J., and Hutchinson, T. C., "A Comparative Study of Heavy Metal Concentrations in River Mouth Sediments Around the Great Lakes." *Jour. Great Lakes Res.*, 1, 46 (1975).
64. Miller, R. W., "The Role of Humic Acids in the Uptake and Release of Mercury by Freshwater Sediments." *Verh. Internat. Verein. Limnol.* (Ger.), 19, 2082 (1975).
65. Thomas, R. L., and Jaquet, J. M., "Mercury in the Surficial Sediments of Lake Erie." *Jour. Fish. Res. Bd. Can.*, 33, 404 (1976).
66. Ramamoorthy, S., and Rust, B. R., "Mercury Sorption and Desorption Characteristics of Some Ottawa River Sediments." *Can. Jour. Earth Sci.*, 13, 530 (1976).
67. Olson, B. H., and Cooper, R. C., "Comparison of Aerobic and Anaerobic Methylation of Mercuric Chloride by San Francisco Bay Sediments." *Water Res.* (G. B.), 10, 113 (1976).
68. Mortimer, D. C., and Kudo, A., "Interaction Between Aquatic Plants and Bed Sediments in Mercury Uptake from Flowing Water." *Jour. Environ. Qual.*, 4, 491 (1975).
69. Chau, Y. K., *et al.*, "Methylation of Selenium in the Aquatic Environment." *Science*, 192, 1130 (1976).
70. Burrows, K. C., and Hulbert, M. H., "Release of Heavy Metals from Sediments: Preliminary Comparison of Laboratory and Field Studies." *In*: Church, T. M. [Ed.], Marine Chemistry in the Coastal Environment. American Chemical Society Symposium Series 18, 382–393 (1975).
71. Brannon, J. M., *et al.*, "Distribution of Manganese, Nickel, Zinc, Cadmium, and Arsenic in Sediments and in the Standard Elutriate." Army Engineers Waterways Expt. Sta., Vicksburg, Miss., Final Report No. WES-MP-D-76-18 (1976); NTIS AD-A026 355 /8SL.
72. Fjerdingstad, E., *et al.*, "Analysis of Heavy Metals and Bacteria in Sediments from Danish Lignite Pits." *Arch. Hydrolbiol.* (Ger.), 77, 226 (1976).
73. Jackson, R. G., and Nichol, I., "Factors Affecting Trace Element Dispersion in Lake Sediments in the Yellowknife Area, N. W. T., Canada." *Verh. Internat. Verein. Limnol.* (Ger.), 19, 308 (1975).
74. Klassen, R. A., *et al.*, "Lake Geochemistry in the Kaminak Lake Area, District of Keewatin, N. W. T." *Verh. Internat. Verein. Limnol.* (Ger.), 19, 340 (1975).
75. Plato, P. A., and Jacobson, A. P., "Cesium-137 in Lake Michigan Sediments: Areal Distribution and Correlation with other Man-Made Materials." *Environ. Poll.*, 10, 19 (1976).
76. Edgington, D. N., and Robbins, J. A., "The Behavior of Plutonium and Other Long-Lived Radionuclides in Lake Michigan. II. Patterns of Deposition in the Sediments." Impacts of Nuclear Releases into the Aquatic Environment, International Atomic Energy Agency, Vienna, 245 (1975).
77. Edgington, D. N., *et al.*, "Plutonium and Americium in Lake Michigan Sediments." Transuranium Nuclides in the Environment, International Atomic Energy Agency, Vienna, 493 (1976).
78. Francis, C. W., and Brinkley, F. S., "Preferential Adsorption of ^{137}Cs to Micaceous Minerals in Contaminated Freshwater Sediment." *Nature* (G. B.), 260, 511 (1976).
79. Noyce, J. R., *et al.*, "Development of a National Bureau of Standards Environmental Radioactivity Standard: River Sediment." National Bureau of Standards, Wash., D. C., Center for Radiation Research (1976); NTIS PB-253 265/3SL.
80. Kobylinski, G. J., and Livingston, R. J., "Movement of Mirex from Sediment and Uptake by the Hogchoker, *Trinectes maculatus*." *Bull. Environ. Contam. Toxicol.*, 14, 692 (1975).
81. Fulk, R., *et al.*, "Laboratory Study of the Release of Pesticides and PCB Materials to the Water Column During Dredging and Disposal Operations." Envirex Inc. Final Report, Army Engineers Waterways Expt. Sta., Vicksburg, Miss. (1975).
82. Choi, W.-W., and Chen, K. Y., "Associations of Chlorinated Hydrocarbons with Fine Particles and Humic Substances in Nearshore Surficial Sediments." *Environ. Sci. & Technol.*, 10, 782 (1976).
83. Kemp, A. L. W., *et al.*, "Cultural Impact on the Geochemistry of Sediments in Lake Erie." *Jour. Fish. Res. Bd. Can.*, 33, 440 (1976).
84. Sasseville, D. R., and Norton, S. A., "Present and Historic Geochemical Relationships in

Four Maine Lakes." *Limnol. & Oceanog.*, **20**, 699 (1976).
85. Ludlam, S. O., "Laminated Sediments in Holomictic Berkshire Lakes." *Limnol. & Oceanog.*, **21**, 743 (1976).
86. Edmondson, W. T., "Microstratification of Lake Washington Sediments." *Verh. Internat. Verein. Limnol.* (Ger.), **19**, 770 (1975).
87. McLachlan, A. J., and McLachlan, S. M., "Development of the Mud Habitat During the Filling of Two New Lakes." *Freshwater Biol.* (G. B.), **6**, 59 (1976).
88. Brown, R. J., "Reservoir and Lake Sedimentation (A Bibliography with Abstracts)." NTIS, Report for 1964–Dec. 75 (1975); NTIS/PS-75/886/2SL.
89. Noltimier, H. C., and Colinvaux, P. A., "Geomagnetic Excursion from Imuruk Lake, Alaska." *Nature* (G. B.), **259**, 197 (1976).
90. Thompson, R., *et al.*, "Magnetic Susceptibility of Lake Sediments." *Limnol. & Oceanog.*, **20**, 687 (1975).
91. Lewis, W. M., Jr., "Observations on the Superficial Sediment Temperatures of Some Lakes in the Southeastern United States." *Freshwater Biol.* (G. B.), **6**, 49 (1976).
92. Thomas, R. L., *et al.*, "Surficial Sediments of Lake Erie." *Jour. Fish. Res. Bd. Can.*, **23**, 385 (1976).
93. Dowling, J. J., "Sedimentation Rates and Sediment Thickness in Lake Champlain." University of Connecticut, Technical Completion Report OWRT-A-066-Conn (1976).
94. Molongoski, J. J., and Klug, M. J., "Characterization of Anaerobic Heterotrophic Bacteria Isolated from Freshwater Lake Sediments." *Appl. Environ. Microbiol.*, **31**, 83 (1976).
95. Zimmerman, A. P., "Electron Transport Analysis as an Indicator of Biological Oxidations in Freshwater Sediments." *Verh. Internat. Verein. Limnol.* (Ger.), **19**, 1518 (1975).
96. Hood, M. A., *et al.*, "Microbial Indicators of Oil-Rich Salt Marsh Sediments." *Appl. Microbiol.*, **30**, 982 (1975).
97. Walker, J. D., *et al.*, "Evaluation of Petroleum-Degrading Potential of Bacteria from Water and Sediment." *Appl. Microbiol.*, **30**, 1036 (1975).
98. Zeikus, J. G., and Winfrey, M. R., "Temperature Limitation of Methanogenesis in Aquatic Sediments." *Appl. Environ. Microbiol.*, **31**, 99 (1976).
99. Balderston, W. L., and Payne, W. J., "Inhibition of Methanogenesis in Salt Marsh Sediments and Whole-Cell Suspensions of Methanogenic Bacteria by Nitrogen Oxides." *Appl. and Environ. Microbiol.*, **32**, 264 (1976).
100. Furukawa, K., and Matsumura, F., "Microbial Metabolism of Polychlorinated Biphenyls. Studies on the Relative Degradability of Polychlorinated Biphenyl Components by *Alkaligenes* sp." *Jour. Agr. Food Chem.*, **24**, 251 (1976).
101. Clesceri, L. S., and Daze', M., "Relations Between Microbial Heterotrophic Activity, Organics, and Deoxyribonucleic Acid in Oligotrophic Lake Sediments." *Verh. Internat. Verein. Limnol.* (Ger.), **19**, 974 (1975).
102. Cranwell, P. A., "Decomposition of Aquatic Biota and Sediment Formation: Organic Compounds in Detritus Resulting From Microbial Attack on the Alga *Ceratium hirundinella*." *Freshwater Biol.* (G. B.), **6**, 41 (1976).
103. Gorham, E., and Sanger, J. E., "Fossil Pigments in Minnesota Lake Sediments and Their Bearing Upon the Balance Between Terrestrial and Aquatic Inputs to Sedimentary Organic Matter." *Verh. Internat. Verein. Limnol.* (Ger.), **19**, 2267 (1975).
104. Griffiths, M., and Edmondson, W. T., "Burial of Oscillaxanthin in the Sediment of Lake Washington." *Limnol. & Oceanog.*, **20**, 945 (1975).
105. Philp, R. P., and Calvin, M., "Possible Origin for Insoluble Organic (Kerogen) Debris in Sediments from Insoluble Cell-Wall Materials of Algae and Bacteria." *Nature* (G. B.), **262**, 134 (1976).
106. Rich, P. H., "Benthic Metabolism of a Soft-Water Lake." *Verh. Internat. Verein. Limnol.* (Ger.), **19**, 1023 (1975).
107. Hargrave, B. T., "Stability in Structure and Function of the Mud-Water Interface." *Verh. Internat. Verein. Limnol.* (Ger.), **19**, 1073 (1975).
108. Miller, M. C., and Reed, J. P., "Benthic Metabolism of Arctic Coastal Ponds, Barrow, Alaska." *Verh. Internat. Verein. Limnol.* (Ger.), **19**, 459 (1975).
109. Neame, P. A., "Oxygen Uptake of Sediments in Castle Lake, California." *Verh. Internat. Verein. Limnol.* (Ger.), **19**, 792 (1975).
110. Pamatmat, M. M., "*In Situ* Metabolism of Benthic Communities." *Cahiers de Biol. Marine* (Fr.), **16**, 613 (1975).
111. Holdren, G. R., *et al.*, "A Model for the Control of Dissolved Manganese in the Interstitial Waters of Chesapeake Bay. *In*: Church, T. M. [Ed.], Marine Chemistry in the Coastal Environment. American Chemical Society Symposium Series 18, 364–381 (1975).
112. Lam, D. C. L., and Jaquet, J. M., "Computations of Physical Transport and Regeneration of Phosphorus in Lake Erie, Fall 1970." *Jour. Fish. Res. Bd. Can.*, **31**, 550 (1976).
113. Hart, B. T., *et al.*, "Nutrient Status of the

Sediments in Lake Mulwala. I. Total Phosphorus." *Australian Jour. Mar. Freshwater Res.*, 27, 129 (1976).

114. Hammond, D. E., *et al.*, "Methane and Radon-222 as Tracers for Mechanisms of Exchange Across the Sediment-Water Interface in the Hudson River Estuary." *In*: Church, T. M. [Ed.], Marine Chemistry in the Coastal Environment. American Chemical Society Symposium Series 18, 119–132 (1975).
115. Thibodeaux, L., and Cheng, C. K., "A Fickian Analysis of Lake Sediment Upsurge." *Water Resources Bull.*, 12, 221 (1976).
116. Bookhout, T. A., and White, G. C., "A Simulation Model of Tritium Kinetics in a Freshwater Marsh." Ohio State University, Water Resources Center, Technical Report W76-10812, Project No. OWRR-A-038-OHIO (1976). NTIS PB-255 761/9SL.
117. Lehman, J. T., "Reconstructing the Rate of Accumulation of Lake Sediment: The Effect of Sediment Focusing." *Quat. Res.*, 5, 541 (1975).